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ABSTRACT

This learning guide provides detailed information about exploring the planet Mars. The guide covers a variety of topics related to space exploration including: (1) the reasons for exploring Mars; (2) a history of the exploration of and thinking about Mars beginning with the Babylonians and continuing through the Viking missions; (3) the status of current exploration projects that include the planet Mars; (4) a discussion of why continuity in the Mars exploration program is important; (5) an outline of future Mars exploration missions that are underway or in the planning stage; and (6) four activities for students. The activities enable students to explore the following: (1) the concept of superposition and the role it plays in ordering planetary events; (2) the connections between geography and mission planning; (3) the Mars canyon system; and (4) impact craters and what can be learned about Mars from studying these geographical features. (DDR)

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Exploring Mars

Subject: Planetary Science
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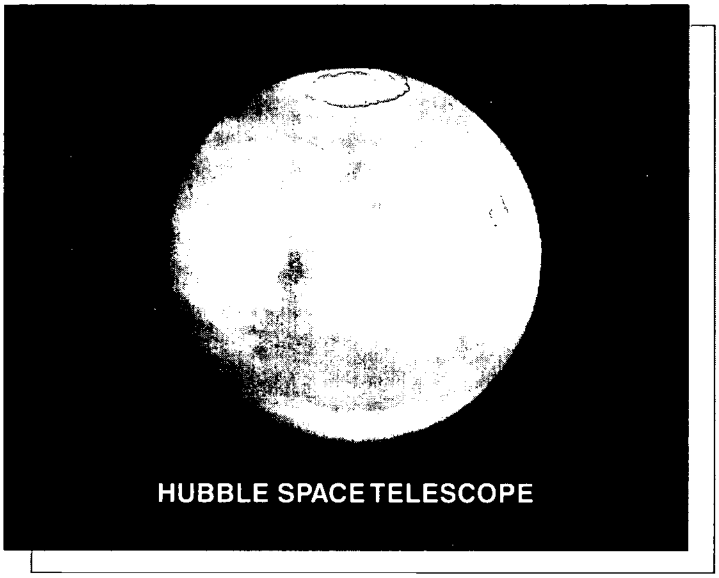
WHY EXPLORE MARS? Why would we explore Mars, the fourth planet from the Sun, the next outward from the Earth? What is there for humankind?

Through a telescope, Mars' red light reveals little detail, an orange round world splashed with gray, white at its poles, rarely obscured by clouds. Close up, Mars is stunning: clouds hovering above lava-draped volcanos; nearly endless chasms, their depths lost in mist; towering ice cliffs striped with red. Mars' past is laid bare in the landscape: impact scars mark world-jarring collisions with asteroids, and deep winding channels recall titanic floods. But robot eyes alone have seen these sights, and then only from orbit high above.

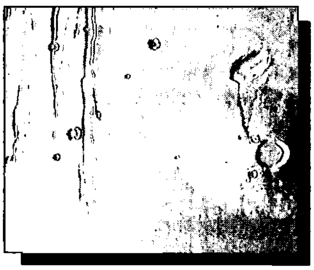
We will find water. Mars is the only planet besides Earth that was ever cut by flowing water or graced by lakes and ponds. Now, that water is frozen at the poles and buried beneath Mars' frigid deserts. In those ancient martian pools, might life have sprung up and prospered? The pools are dry and sterile today, but could life persist in deep and hidden places? Someday, will humans walk those distant deserts, seeking signs of ancient life?



Mars seen from Earth orbit.

A HISTORY OF EXPLORATION

Humans have known of Mars since before recorded history. Even 3600 years ago, the Babylonians wrote about Mars' looping motion across the sky and changing brightness. Mars was one of five "stars that wandered" among the fixed stars of the night, and was special because of its color: red. In ancient India, Mars appeared like a fire in the sky—for many other cultures, its redness recalled the fire and blood of war. In ancient Greece, the red wanderer personified the god of war, "Ares." When the Romans conquered Greece, they adopted this symbolism and named the planet for their god of war, "Mars."



Ceraunius Tholus volcano on the Tharsis Rise. The scene is 215 kilometers across.

Through the Middle ages, astrologers studied Mars' motions to help them predict the future—if Mars moved unfavorably, wars would be lost! But no one could predict Mars' motion accurately, even using Copernicus' theory (of 1543) that the planets orbit in circles around the Sun. Johannes Kepler solved this puzzle in 1609 when he discovered that Mars orbits the Sun in an ellipse, not a circle. Seventy-five years later, Kepler's solution was crucial to Isaac Newton's study of gravity.

While Kepler explained its orbit, Galileo Galilei transformed Mars into a world. In 1609, Galileo first viewed Mars through his newly invented telescope. Although his telescope was no better than a modern toy, it revealed enough to prove that Mars was a large sphere, a world like the Earth. Could this new world be inhabited? As telescopes improved, more of Mars could be seen: polar icecaps, color patterns on its face, clouds, and hazes. These observations all fit a habitable planet, and speculations that Mars was inhabited became more and more believable.

The idea of living martians came to full flower in 1877 when the Italian astronomer Giovanni Schiaparelli observed thin dark lines crossing Mars' bright "continents." He called the lines "canali," "channels" in Italian, and the word was widely misread as "canals." In the U.S., Percival Lowell seized on the canals as proof of a martian civilization, advanced enough to move water across a whole world. Many scientists agreed, but most thought that the canals were optical illusions. They thought that Mars was too cold and its air too thin for life as we know it.

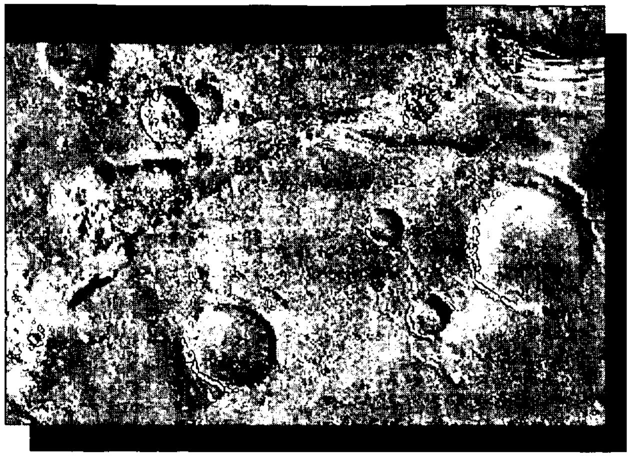
Understanding of Mars advanced little from Lowell's time in the late nineteenth century until 1965, when the **Mariner 4** spacecraft flew within 10,000 kilometers of the martian surface. Its pictures, the first close-up views of Mars, showed a Moonlike landscape of plains pocked by impact craters. There were no canals or other signs of life. Mariner 4 finally proved that Mars' atmosphere, only 0.7% as thick as the Earth's, was much too thin for life as we know it.

Four years later the twin spacecraft **Mariner 6** and **Mariner 7** flew by Mars again, carrying cameras and spectrometers to measure the temperature of Mars' surface and the composition of its atmosphere. Their photos again showed no canals or other signs of life, but did reveal a volcano, plains without impact craters, and areas of unusual hummocky (chaotic) terrain. Mars' mass and density were calculated from spacecraft tracking. The spectrometers showed that Mars was very cold (–123°C at the south pole), and that Mars' thin atmosphere was almost all carbon dioxide. At the time, Apollo 11's landing on the Moon overshadowed the successes of Mariners 6 and 7.

Exciting as they were, the early Mariners only spent a short time near Mars as they flew past; more time was needed, and that meant going into orbit. So in 1971, **Mariner 9** arrived at Mars and became the first artificial object ever to orbit another planet. More than twice as big as its predecessors, Mariner 9 carried color cameras and new instruments tailored to investigating Mars' surface and atmosphere. An unsung part of the spacecraft was its computer system, which allowed Mariner 9 to wait until Mars' atmosphere cleared of a planetwide dust storm. Mariner 9 operated for almost a year, mapped 85% of Mars' surface in more than 7000 images, analyzed Mars' gravity field, measured surface temperatures and dust abundances, and measured temperatures and humidity of its atmosphere.

Mariner 9's view of Mars was the first detailed global view of another planet; it revealed a "New Mars," unlike any earlier concept. The earlier Mariners saw land typical of the southern

The summit of Olympus Mons volcano. The caldera at its summit is 65 × 80 kilometers.



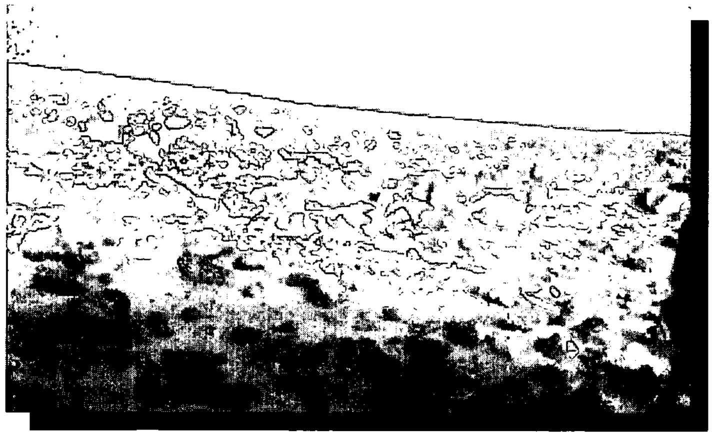
A 300-kilometer portion of the Ravi Vallis canyon, which was cut by a giant flood.

hemisphere: craters and more craters. Mariner 9 saw what they missed. First, the Valles Marineris, a canyon up to 100 kilometers wide and 10 kilometers deep that would reach from Los Angeles to New York! Giant valleys extend from the Valles and elsewhere, mute testimony to devastating floods in Mars' distant past. Most of the valleys end in the northern plains, a vast lowland encompassing almost a third of the planet. There, the floodwaters ponded into huge lakes or even an ocean. Signs of water appeared in the southern highlands too, for the most part as small valleys draining away from the largest craters and uplands. Despite these signs of ancient water, Mars now is too cold and its atmosphere too thin for liquid water to remain.

Mariner 9 also was the first to see Mars' volcanos, the biggest in the solar system. The biggest of all, Olympus Mons, is 600 kilometers across at its base and 25 kilometers tall. Smaller volcanos and lava flows appear all over Mars, especially on the Tharsis Rise, a huge bulge distorting Mars' spherical shape. Looking toward space, Mariner 9 took the first close-up images of Mars' moons, Phobos and Deimos. They are little more than large potato-shaped rocks, about 10 kilometers long, and appear similar to asteroids.

Mariner 9's global perspective and spectacular images of water-carved landscapes inspired further exploration of Mars to focus on the search for life. After extensive development, the twin spacecraft **Viking 1** and **2** were launched in 1975 and entered Mars orbit in 1976. Each Viking was actually two spacecraft: an orbiter and a lander. Each orbiter had a pair of cameras and instruments for mapping surface temperature and atmosphere humidity. Each lander included a weather station, a seismometer for detecting "marsquakes," instruments for analyzing soil, and a stereo TV camera.

The Viking 1 lander touched down gently on July 20, 1976, on Chryse Planitia in the northern lowlands. Its robot eyes took the first photos of the martian surface: a rolling desolation of dark rounded rocks and brick-red dust under a pink sky. The rocks are probably volcanic, pitted and smoothed by eons of blowing sands. On landing, though, the winds were light, at most 30 kilometers per hour. Viking 1 sits at a latitude comparable to the Sahara Desert on Earth, but its daytime temperatures climbed to a high of –10°C, and dropped to a numbing –90°C before sunrise.

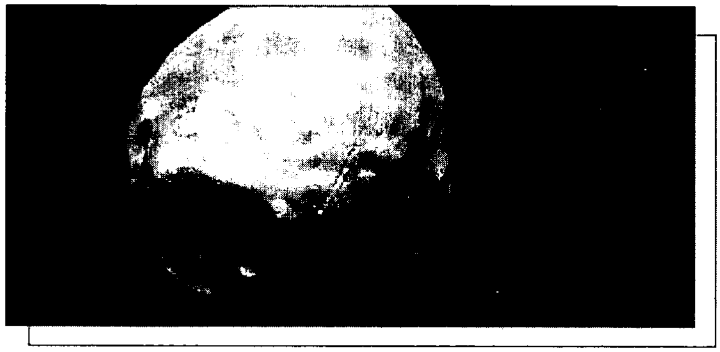


Dark rocks and white frost at the Viking 2 lander site. The largest rocks are about 1 meter long.

The Viking 2 lander alit a few months later on Utopia Planitia, closer to Mars' north pole, a latitude comparable to Maine or Mongolia on Earth. The plains of Utopia are rockier than the Viking 1 site in Chryse; one of Viking 2's legs stands on a rock. The landscape at Utopia is nearly flat; only a few low crater hills appear on the distant horizon. In the summer, Utopia was no warmer than Chryse, but its winter night temperatures plunged to −120°C. In winter, sunrise frost was often evident on the rocks and sand, but it soon vanished into the dry air.

The Viking landers saw nothing alive, and recorded no movement except blowing sand, shifting dunes, and their own robot arms. The arms pushed and scraped the martian soil, and scooped some for analysis. The landers' soil instruments were designed to detect Earthlike life. The instruments cooked soil, soaked it, and fed it nutrient broth. Although the soil contained no organic material, a few experiments seemed to indicate living organisms. After years of debate, almost all scientists now agree that the life signs came from unusual minerals in the soil, and that Mars' surface is lifeless.

Meanwhile, the two Viking orbiters sailed overhead, recording the martian landscape. Instruments measured water abundances in the atmosphere and temperatures on the surface, both day and night. The orbiters took more than 52,000 images, giving complete coverage of Mars in great detail. These images have fueled years of intense study of Mars, and are still yielding new insights into its volcanos, water, and ancient history.



Mars' larger moon, Phobos. The crater on the near end is 10 kilometers in diameter.

EXPLORATION NOW

There has been little new from Mars since the Viking missions, but many new spacecraft explorations are planned for the next decades. Between the time of the Viking missions and 1996, only three spacecraft went to Mars and only one, the Russian PHOBOS 2, returned any useful data. PHOBOS 2 entered Mars orbit in January 1989 and started taking images of Mars and its moon Phobos in infrared light. But in March, PHOBOS 2 lost contact with Earth and never began its planned close approach to Phobos.

Without spacecraft at Mars, the Hubble Space Telescope has been one of the few highlights of Mars exploration. Hubble cannot see surface details smaller than about 50 kilometers, but can see Mars well enough to map global temperature, weather, and color changes. Measurements from Hubble show that Mars' atmosphere is now colder and much less dusty than during the Viking missions; its sky is probably blue-purple instead of pink from dust. Clouds of water ice are more abundant now than during the Viking missions, and show how water moves from pole to pole as Mars' seasons change.

Another highlight in Mars exploration is the discovery that a few meteorites on Earth came originally from Mars! These meteorites contain traces of gas identical to the martian atmosphere as analyzed by the Viking landers. Asteroid impacts ejected the meteorites off Mars into orbit around the Sun; after millions of years, they landed on the Earth. The martian meteorites are all volcanic rocks, most are young (erupted only 180 million years ago), and almost all have reacted with martian groundwater. These meteorites have revolutionized thinking about Mars' atmosphere and its water, and are "ground truth" for interpreting images of the distant geology of Mars. The martian meteorites are almost like sample return missions, except we don't know where on Mars they formed. The most exciting news is that one martian meteorite may have traces of ancient martian life — fossilized martian bacteria!

The martian meteorite EETA 79001, found in Antarctica. The cube beside the meteorite is 1 centimeter on a side.

WHY CONTINUE?

Is there any reason to continue exploring Mars? Haven't we learned everything already? Telescope and spacecraft exploration have taught us a lot, but many important questions remain unanswered.

For instance, why is Mars' surface (with many craters and huge volcanos, and no continents) different from the Earth's surface (with continents and chains of smaller volcanos, but few craters)? The answer seems to lie deep within the planets, where hot rock flows slowly upward toward the surface. This motion is called mantle convection, and it seems to take different forms on the Earth and Mars. On the Earth, mantle convection moves large pieces of the surface, the geologic plates, and most volcanos, earthquakes, and mountains form at plate boundaries. On Mars, however, the upward flow of mantle rock bows up the surface but doesn't break it into pieces. The upward flow is centered at Tharsis, a bulge or high plateau about 4000 kilometers across and up to 10 kilometers high. Tharsis is covered by volcanos that reach even higher; Olympus Mons is 25 kilometers tall. It appears that the volcanos on Tharsis have erupted for almost the whole history of Mars. The Tharsis volcanos might still be active but dormant — no volcano eruptions have ever been seen. Around Tharsis are many long cracks (including the Valles Marineris), showing that the martian crust was stretched and broken as Tharsis swelled. The high elevations, volcanos, and cracks were all caused by mantle convection. But compare this stable pattern with the Earth, where mantle convection produces chains of volcanos and long mountain ranges that come and go through time.

Another question: Why doesn't Mars have oceans like the Earth does? Mars' atmosphere is now too thin and its temperature too cold to allow liquid water. But the important questions are about water itself — how much water does Mars have, and where is it? Mars certainly had surface water and groundwater once; only liquid water could have shaped the valley networks in the highlands and the huge flood channels that cut from the highlands to the northern lowlands. But how much water was there? Estimates range from the equivalent of an ocean 10 meters deep covering the whole surface to the equivalent of a layer kilometers deep. The first is not much water at all, and the second is a lot of water! However much water there was, it is not now on the surface, except for a bit in the polar ice caps. Where did the water go? It could be underground in pools of groundwater, either small or huge depending on how much water Mars started with. Or it could have escaped to space and been lost completely — the hydrogen from water can escape easily through Mars' low gravity and small magnetic field.

And finally, we don't know if there is or was life on Mars. There are no canals or ancient cities, and no clear signs of any life on Mars' inhospitable surface. But Mars' climate was mild once, with a thicker atmosphere, flowing water, open lakes, and perhaps even an ocean. Life on Earth may have started under similar conditions, possibly at underwater hot springs. With its volcanos and lava flows, Mars probably also had hot springs — if Mars had oceans or lakes, could life have also started on Mars? We know about the origins and history of life on Earth from fossils — how and where would we look for fossils on Mars? And why confine our search to Mars' surface? On Earth, many kinds of bacteria live deep inside rocks, and die when exposed to light and fresh air. Could organisms like these be alive and prospering in groundwater far beneath the surface of Mars? And do we now have fossils of these bacteria, preserved for eons in the martian meteorites?

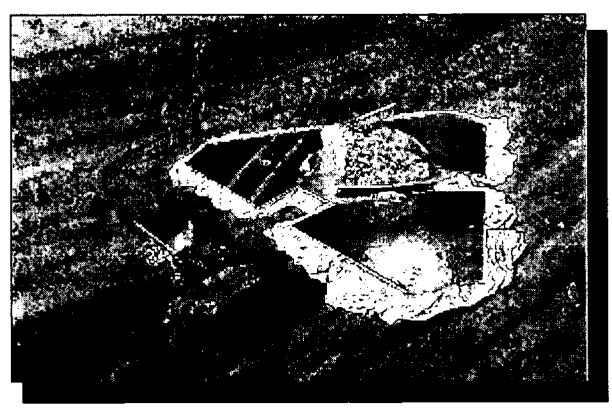
THE FUTURE

Some of these important questions about Mars may be answered in the next few years by robotic spacecraft.

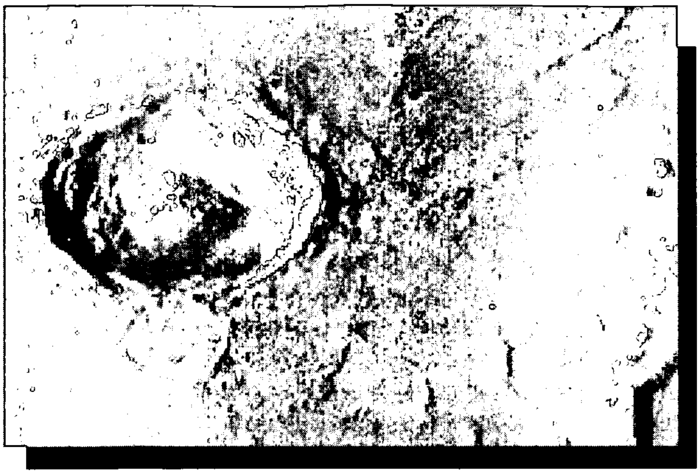
Mars Pathfinder, the first Mars lander since Viking 2, was launched in December 1996. It will land in 1997, nestled among four airbags to cushion its fall. After landing, Pathfinder will open like a three-petal flower; each petal is a solar cell panel. The spacecraft body, among the petals, will contain the computer control and communications system. Above the body will rise a camera system, which will take full-color stereo pictures of the landing site. The camera is also sensitive to infrared light, which will help determine what kinds of rocks and soils are there. Instruments to measure wind speed, temperature, and pressure will stand on a rod above a petal.

Pathfinder carries a small rover, named Sojourner, that will drive off a petal soon after landing. The rover is only 65 centimeters long and weighs only 10 kilograms. It will travel slowly, avoiding big rocks and holes with its stereo camera and computer "hazard avoidance system." Also on board are a close-up camera and a chemical analyzer, which are essential for understanding the soils and rocks that Sojourner meets.

The **Mars Global Surveyor** spacecraft was also launched in 1996 to orbit Mars, and reflies many of the science instruments on the lost **Mars Observer** spacecraft. To provide global weather coverage and detailed images of the surface, Mars



Artist's conception of the Mars Pathfinder spacecraft and its rover, Sojourner.



The impact crater Yuty, 18 kilometers in diameter. It formed when a large meteorite hit Mars.

Global Surveyor will carry a color camera. With its telephoto lens, objects as small as 2 meters should be visible; we might see the Viking landers or their shadows! Mars Global Surveyor will measure elevations by bouncing laser light from the spacecraft off of Mars' surface, and measuring how long it takes the light to return to the spacecraft; there are still questions about the heights of volcanos and the depths of the chasms. Temperatures on Mars' surface will be mapped by a thermal spectrometer; will it find hot spots from active volcanos, geysers, or springs? The thermal spectrometer will also map out the distribution of minerals and rocks on Mars. Variations in Mars' gravity will be mapped from changes in the spacecraft's speed; this subtle measurement helps locate heavy and light rock masses beneath Mars' surface. A magnetometer will determine whether Mars has its own internal magnetic field, like the Earth does.

Space exploration is a challenging and complex endeavor. The Russian-led international **Mars 96** spacecraft was also launched in November 1996, but it failed to escape Earth's gravitational pull because of a rocket malfunction. All its scientific instruments, including an orbiter, two penetrators, and two small landers, were lost.

In a few years, even more spacecraft will be headed toward Mars. Next in line are the **Mars Surveyor 98 Orbiter and Lander,** slated for launches in late 1998 and early 1999. The **98 Orbiter** will fly a new lightweight color camera for weather and surface images. Its other instrument will be a complex detector for infrared light, which will give temperatures and pressures throughout the atmosphere. The **98 Lander** will be the first mission to the martian poles, where it will descend onto deposits of dusty ice. The Lander will carry cameras, a robot arm with a scoop, a chemical analyzer, and weather instruments. Beyond 1998, missions to Mars are planned for every opportunity (every two years); many will be collaborations with other countries. The missions might include networks of weather and "marsquake" stations, a landing in an ancient lakebed or in the Valles Marineris, a search for groundwater using radar, or a return of martian samples to Earth!

When will humans explore Mars? No space agency has serious plans for human landings on Mars in the near future; landings before 2020 are probably impossible. But someday, people will descend from a spacecraft, stand on red soil, and see for themselves the canyons, volcanos, and dried lakebeds of Mars.

U.S. MARS MISSIONS—SUCCESSFUL AND PLANNED

MISSION	LAUNCH	ARRIVAL	HIGHLIGHTS
Mariner 4 Flyby	Nov. 28, 1964	July 14, 1965	22 black and white images of desolate, cratered southern hemisphere. No canals or signs of life. Water frost seen. Proof that Mars' atmosphere is very thin.
Mariner 6 and 7 Flybys	Feb. 24 and Mar. 27, 1969	July 31 and Aug. 5, 1969	75 and 126 black-and-white images of equatorial region, southern hemisphere, and south polar ice. Measured Mars' mass and density.
Mariner 9 Orbiter	May 30, 1971	Orbit: Nov. 14, 1971	7329 images, many in color. Global maps of elevation, temperature. First views of huge volcanos of Tharsis, chasms of Valles Marineris, water-cut channels, Mars' moons.
Viking 1 Orbiter, Lander	Aug. 20, 1975	Orbit: June 19, 1976 Landing: July 20, 1976	Orbiter gives >30,000 images of surface, many in color. Global maps of temperature, atmosphere water content, surface properties. Lander gives first images from Mars' surface: dark rocks, red dust, pink sky. Tests soil for life and finds none. Records Mars weather.
Viking 2 Orbiter, Lander	Sept. 9, 1975	Orbit: Aug. 7, 1976 Landing: Sept. 3, 1976	Like Viking 1, Orbiter gives >20,000 images of surface. Lander finds no life; again dark rocks, red dust, pink sky. Records Mars weather.
Mars Global Surveyor, Orbiter	Nov. 7, 1996	Planned for Sept. 1997	Global weather imagery, surface topography and temperatures.
Mars Pathfinder Lander	Dec. 4, 1996	Planned for July 4, 1997	Landing in Ares Valles; engineering tests, imaging and chemical investigations.
Mars Surveyor Orbiter 1998	Planned for Dec. 1998		Global imagery, atmospheric temperature profiles.
Mars Surveyor Lander 1998	Planned; Jan. 1999		First landing near martian poles.

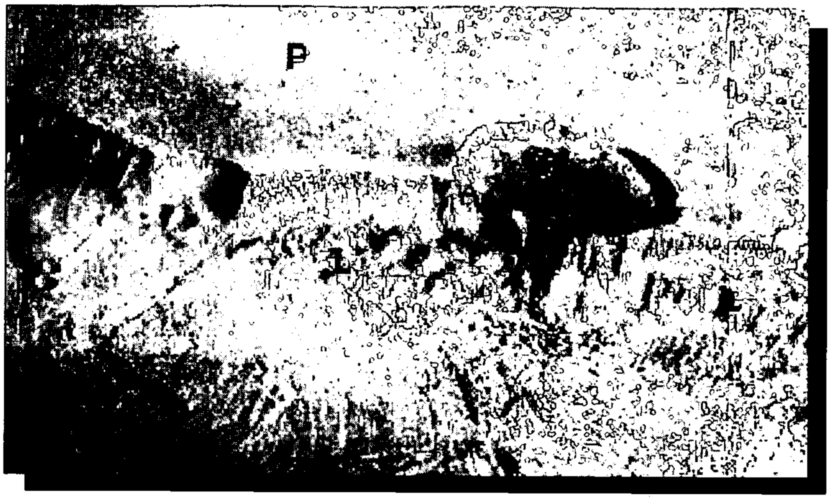


Fig. 1. *Craters and landslides at the wall of Valles Marineris. Viewed at an angle, scene is 60 kilometers across.*

Activity 1: Old, Relatively

For exploring Mars, it is important to know which events happened in which order, and which areas are older than others. A simple way of figuring out the sequence of events is **superposition**—most of the time, younger things are on top of older things, and younger (more recent) events affect older things.

1a. *Superposition in your life.* Is there a pile of stuff on your desk? On your teacher's? On a table or the floor at home? Where in the pile is the thing you used most recently? The thing next most recently? Where in the pile would you look for something you put down 10 minutes ago? When was the last time you (your teacher or your parent) used the things at the bottom of the pile?

1b. *Superposition on Mars.* Using superposition, we can sort out many of the complicated events in the history of Mars. For example, you can sort out all the events that affected the area of Fig. 1, which shows a small part of the wall of the great canyon system of Valles Marineris. Toward the top of the picture is a high plateau (labeled "P" on the picture), with a large circular impact crater ("C"). It formed when a huge meteorite hit Mars' surface. Below the plateau is the wall of Valles Marineris. Here, the wall has been cut away by huge landslides ("L"), which leave bumpy rough land at the base of the wall and a thin, broad fan of dirt spreading out into the canyon floor. In the canyon wall, almost at its top, alternating layers of light and dark rock are exposed.

To discover the history of this part of the Valles Marineris, start by listing all the landscape features you can see, and the events that caused them (don't bother listing every small crater by itself). Now list the events in order from oldest to youngest. [Hints: How many separate landslides are there? Is the large crater ("C") younger than the landslides? Are the landslides younger than the rock layers at the top of the walls? Are the small craters older or younger than the landslides?] Sometimes, you cannot tell which of two events was younger. What additional information would help you tell? To learn more about this image, visit the Internet site **http://cass.jsc.nasa.gov/education/K12/gangis/mars.html**

Activity 2: Geography and Mission Planning

These locations, on Mars, were considered as possible landing sites for the Viking missions.

Latitude	Longitude		
1. 22°N	48°W		Viking 1 Site
2. 20°N	108°E		
3. 44°N	10°W		
4. 7°S	43°W		
5. 46°N	150°W		Viking 2 Site
6. 44°N	110°W		
7. 5°S	5°W		

2a. If martians sent spacecraft to these same latitudes and longitudes on Earth, what would they find? Would they find life or an advanced civilization?

2b. If you were a martian, why would you explore the Earth? Does Earth have resources you might need? What would you want to know about the Earth? Where would you land first? (From B. M. French, *The Viking Discoveries,* NASA EP-146, Oct. 1977)

When large meteorites strike a planet's surface, they leave impact craters. Meteor Crater in Arizona is the most famous of the 150 impact craters known on Earth. During a meteorite impact, rocks from deep in a planet are gouged up and thrown onto the surface, so impact craters can be used like a mine or drill hole to show us rocks from underground. Also, the abundance of impact craters on a surface shows its age—the more craters on a surface, the older it must be.

3a. *Crater Excavations: Laboratory Experiment.* Start with a flat sand surface: A playground sandbox is ideal, but any unbreakable box with a surface bigger than about 2' × 2' will do. Smooth the sand surface, and cover the sand with a layer of fine, contrasting powder: different sand, tempera paint powder, or colored sugar work well. Cover this layer with about a few millimeters of sand. Then throw marbles or gravel into the sand, and see if your crater can excavate the contrasting layer. How deep is your crater? How far was the contrasting powder thrown by the impact? This experiment can be expanded and quantified by experiments with different types of sand, different depths of burial, marbles of different sizes and weights, and different angles of impact. Using a slingshot to shoot the marbles will permit harder impacts and bigger craters, but careful supervision is required.

3b. *Craters Old and New: Laboratory Experiment.* Make many craters on a smoothed sand surface by throwing gravel or marbles until the sand is evenly peppered with craters. Then smooth out half the sand surface, erasing all its craters. Resume throwing gravel or marbles at the sand, but only throw about half as many as before. Now, half the sand surface should be heavily cratered and the other half moderately cratered. If you hadn't seen it happen, could you tell which part of the sandbox was smoothed during the experiment?

3c. *Resurfacing—Some Thought Questions.* Many processes on planets can erase, or smooth out, earlier landscapes. The word for this is resurfacing, literally putting a new surface on the land. What processes on Earth act to resurface its land? Compare Fig. 2 with a map or aerial photo of a place you know—why does Mars have more craters than your place? Find a globe or map of the Moon—what resurfacing processes act on the moon? Can impacts resurface a landscape?

3d. *The Sandbox of Mars.* Fig. 2 shows an area in Mars' southern hemisphere. On the figure or a photocopy, sketch or trace out all the circular rim craters you find (also outline incomplete circles). Then, draw a boundary line that separates areas with many craters from areas with few or no craters. Which of the two areas is younger? Remember that liquid water cannot exist on Mars' surface now—what processes that don't require water could have resurfaced Mars? Look at the long, twisting feature that goes from the upper right corner to the middle of the left side of Fig. 2. Does anything on your state map have the same kind of swerving path? The feature might be a river bed, now bone dry (of course). What was Mars' climate like when water flowed in that river? What happened to the water that once flowed in the river bed? Where is it now?

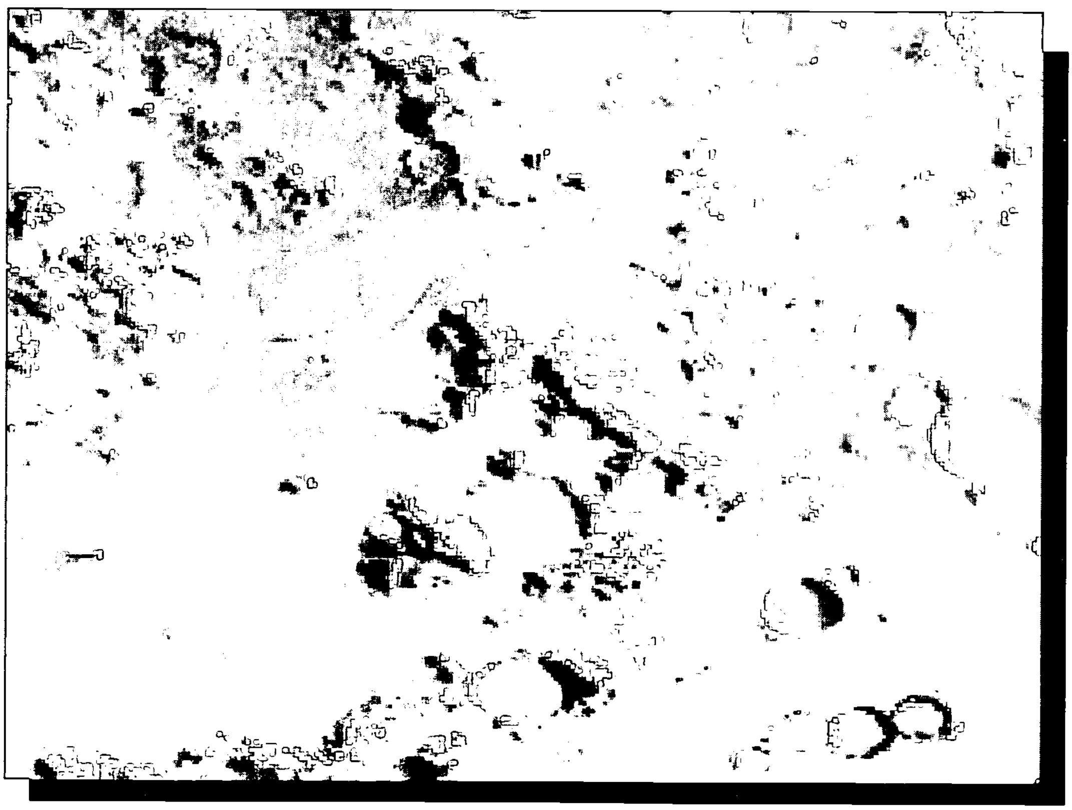


Fig. 2. *Ancient cratered highlands of Mars, east of the Hellas Basin. Scene is about 300 kilometers across.*

The great canyon system of Valles Marineris stretches 4000 kilometers across Mars. Figure 3 shows part of Ius Chasma, the southwestern part of the Valles Marineris.

4a. *Working for Scale (Geography and Math).* The scene of Fig. 3 is 600 kilometers east-to-west (left to right). At this scale, how many centimeters (or inches) on the figure represent 100 kilometers on Mars? How many kilometers from the top of the scene to the bottom? How big is the largest impact crater in the scene? How far is it across your home town?

Sketch the outline of your home state at this same scale - would it fit inside Ius Chasma? Which states would fit inside? Ius Chasma is about 5 kilometers deep. For comparison, how tall (in kilometers) is Mt. Everest, the tallest mountain on Earth? How tall is Mt. McKinley (Denali), the tallest in North America?

Find a map of Arizona or the western U.S. that shows the Grand Canyon. Trace the path of the Colorado River as it flows through the Grand Canyon. Now redraw your sketch at the same scale as Fig. 3. Which canyons in Fig. 3 are comparable to the Grand Canyon? How wide is the Grand Canyon, and how wide are the canyons on the south side of Ius Chasma?

Advanced: Imagine you are standing on the floor of Ius Chasma at its south wall, at the very eastern edge of Fig. 3. How tall does the north wall of the Chasma appear to be? As tall as a telephone pole seen from a block away? Did you consider that Mars is a spherical planet (more or less) and that its surface is curved?

4b. *Straight and Crooked Paths.* Ius Chasma is basically straight because its edges follow huge geologic faults. On a map of your home state, trace out the channels of rivers and streams; are any of them straight like Ius Chasma? From a map of Arizona, trace the main channels and canyons in the Grand Canyon. Is the Grand Canyon as crooked as the canyons on the south wall of the Chasm? Find the East African Rift on a topographic map of Africa. The Rift's walls are huge geologic faults—are any parts of the Rift as long and straight as Ius Chasma?

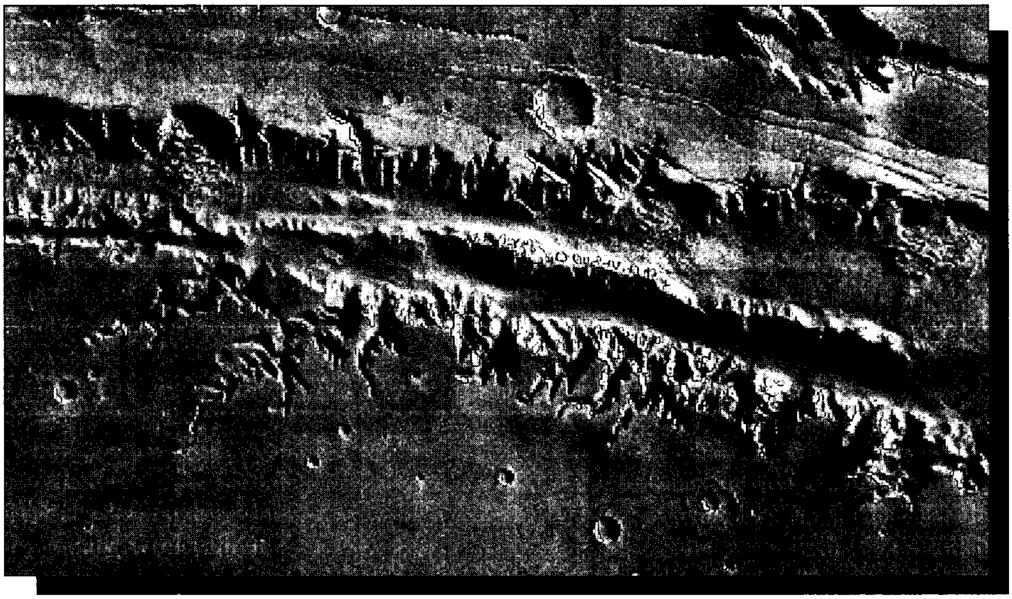


Fig. 3. *A part of Ius Chasma in the Valles Marineris canyon system. Viewed straight down, the scene is 600 kilometers across.*

For More Information

Carr M. (1981) *The Surface of Mars* (book) Yale.
Wilford J. N. (1990) *Mars Beckons* (book) Knopf.
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